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A new species of *Bocchus* from upper Eocene Rovno amber (Hymenoptera, Dryinidae)

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Abstract

A new fossil species of Dryinidae (Hymenoptera, Chrysidoidea) from upper Eocene Rovno amber (Ukraine) is described: *Bocchus rex* **sp. nov.** It is compared with two other species of *Bocchus* known from European amber: *B. primaevus* Martins & Melo from Baltic amber and *B. schmalhauseni* Perkovsky, Olmi, Vasilenko, Capradossi & Guglielmino from Rovno amber. A new key to the Cretaceous and Paleogene species of *Bocchus* is presented. The Dryininae are the most common representatives in all the amber dryinid faunas since the mid-Cretaceous. The Rovno amber fauna is an exception; possible explanations for the abundance of *Bocchus* species within this amber are presented.

Keywords

Bocchinae, *Bocchus rex*, Chrysidoidea, key, systematics

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Introduction

Dryinidae (Hymenoptera, Chrysidoidea) are parasitoids of Auchenorrhyncha (Hemiptera) (Olmi 1984; Guglielmino et al. 2013). This family is present in all continents, except for Antarctica, and comprises about 1900 species (Olmi et al. 2021a).

Eighty fossil species of Dryinidae have been described, among which the following six have been recorded from upper Eocene Rovno amber (Ukraine; 35–38 Ma) (Martynova et al. 2019; Perkovsky et al. 2020; Olmi et al. 2022): Bocchinae: *Bocchus schmalhauseni* Perkovsky, Olmi, Vasilenko, Capradossi & Guglielmino, 2020; Dryininae: *Dryinus janzeni* Olmi, 2000, *D. reifi* Olmi & Bechly, 2001, *D. wunderlichi* Olmi & Bechly, 2001; Apodryininae: *Rovnodryinus khomychi* Olmi, Guglielmino, Vasilenko & Perkovsky, 2022; Palaeoanteoninae: *Palaeoanteon janzeni* Olmi, 2000. In contrast, Baltic and Scandinavian amber (coeval of Rovno amber) are known to include 21 and two species of Dryinidae (Martynova et al. 2019; Olmi et al. 2021b), respectively. All known specimens from Ukraine have been collected in the Varash district of the Rovno region (which includes the former Vladimirets and Zarechnoye districts) and most of the important new taxa described from Rovno amber during the last few years (Matalin et al. 2021; Perkovsky and Nel 2021; Tshernyshev and Perkovsky 2021; and references therein).

Recently, we received two pieces of Rovno amber: one from a site in the Volyn region adjacent to the Varash district and the second most probably from the Varash district. They included specimens of Dryinidae that proved to belong to a new species, which we describe below.

Materials and methods

Terms

The description follows the morphological terminology of Olmi et al. (2019). All measurements reported are relative, except for the total length (head to metasomal tip, without antennae and sting). Antennal proportions refer to the lengths of the relevant segments as proportions of each other, with the values rounded to the nearest whole number. The following abbreviations are used: POL, distance between the inner edges of the two lateral ocelli; OL, shortest distance between the edge of a lateral ocellus and the median ocellus; OOL, distance from the outer edge of a lateral ocellus to the compound eye; OPL, distance from the posterior edge of a lateral ocellus to the occipital carina; TL, distance from the posterior edge of the eye to the occipital carina.

The term "disc of metapectal-propodeal complex" is used here in the sense of Kawada et al. (2015) and Lanes et al. (2020). It corresponds to the term "dorsal surface of propodeum" *sensu* Olmi (1984) and Olmi et al. (2019). The term "propodeal declivity" *sensu* Kawada et al. (2015), used here, corresponds to the term "posterior surface of propodeum" *sensu* Olmi (1984) and Olmi et al. (2019). The names of veins of the fore wing are here used in the sense of Azevedo et al. (2018) and Lanes et al. (2020). The "stigmal vein" (*sensu* Olmi 1984 and Olmi et al. 2019) is named here the "second radial cross & radial sector (2r-rs&Rs)".

The term "ADOs" (= Antennal Dorsal Organs) is used here in the sense of Riolo et al. (2016). It corresponds to the term "rhinaria" *sensu* Olmi (1984). According to Riolo et al. (2016), ADOs are sensory structures that might mediate the antennal responses to vibratory stimuli. As far as we know, they are usually present in the antennae of dryinid females attacking Fulgoromorpha (Perkovsky et al. 2019).

Specimens

The specimens studied in this paper have been deposited in the following collections:

Specimen 1: Schmalhausen Institute of Zoology (SIZK), National Academy of Sciences of Ukraine, Kiev, Ukraine.
Specimen 2: State Museum of Natural History Stuttgart (SMNS), Stuttgart, Germany.

Stereomicroscopy

The multifocal photos were taken using a mirrorless Sony Alpha 6100 camera (Sony Group Corporation, Tokyo, Japan), with Canon bellows and three-way revolver for optical microscopy (Canon Inc., Tokyo, Japan). The following objectives were used: LOMO 3.7 × 0.11 (LOMO, St. Petersburg, Russia) for magnifications from 20 to 50×; Zeiss Semiplan 6.3 × 0.11 (Carl Zeiss GmbH, Jena, Germany) for magnifications from 50 to 100×. The motorized focus was managed by a Cognisys stackshot controller (Cognisys Inc., Traverse City, MI, USA). Captured images were merged into a single in-focus image by using ZereneStacker™ version 1.04 (Zerene Systems LLC, Richland, WA, USA). Images were processed with GIMP version 2.10.30 (https://www.gimp.org).

Synchrotron X-ray phase-contrast microtomography (SR-μCT) and image processing

Synchrotron X-ray microtomography (SR-μCT) (Betz et al. 2007) was performed at the UFO-I station of the Imaging Cluster at the KIT light source of Karlsruhe Institute of Technology (KIT, Karlsruhe, Germany) by using a parallel polychromatic X-ray beam produced by a 1.5 T bending magnet. Specimen 2 was glued onto a plastic pin and mounted onto the goniometer head of the sample stage for tomography. The beam was spectrally filtered with 0.5 mm aluminium with a spectrum peak around 15 keV and a full-width at half maximum bandwidth of about 10 keV. A fast indirect detector system was employed, consisting of a 13 μm LSO:Tb scintillator (Cecilia et al. 2011), diffraction limited optical microscope (Optique Peter) (Douissard et al. 2012) and a 12bit pco.dimax high-speed camera with a resolution of 2016 × 2016 pixels; 3000 projections were recorded at 70 frames per seconds and an optical magnification of 10×, resulting in an effective detector pixel size of 1.22 μm. Two separate overlapping image stacks were acquired because the specimen was larger than the field of view. Therefore, the sample was repositioned in between the imaging procedure, resulting in

a certain overlap of two consecutive images. The control system concert (Vogelgesang et al. 2016) was used for automated data acquisition and online reconstruction of tomographic slices for data quality assurance. Execution of the pipelines, including online tomographic reconstruction, was performed by the UFO framework (Vogelgesang et al. 2012). Final tomographic reconstruction was carried out with *tofu* (Faragó et al. 2022).

The two resulting tomograms were registered and calibrated with Fiji (Schindelin et al. 2012) (https://imagej.net/Fiji) and further imported to the plugin TrakEM2 (Cardona et al. 2012) for stitching and cropping. Subsequently, the resulting image stack was imported to Amira version 6.0 (FEI Company, Hillsboro, OR, USA) to presegment the various cuticular and internal structures in the software's segmentation editor by manually labelling every 50th virtual slice. These labels served as an input for automated segmentation by using the Biomedical Image Segmentation App 'Biomedisa' (Lösel et al. 2020) (https://biomedisa.org). After some minor manual corrections to the segmentation results of the 'Biomedisa' output by using Amira, we converted them into polygon meshes. We thereby applied some minor smoothing and polygon reduction to create the final 3D model (surface mesh).

Results

Bocchus rex sp. nov.

https://zoobank.org/C24153EA-53FD-40CD-96FB-08BEA582D2BE

Type material. ***Holotype*** (= specimen 1; Fig. 1): f#, in SIZK: Ukraine: Les-1, specimen in upper Eocene Rovno amber, collected in Lisove amber mine in Volyn Region of W Ukraine, 9 km east of Manevichi (the former Manevichi district, now Kamen-Kashirsky district). Horizon: Priabonian (35–38 Ma). ***Paratype*** (= specimen 2; Figs 2, 3): 1f#, in SMNS: UKR-1, specimen in Rovno amber (unknown locality).

Diagnosis. Macropterous female of *Bocchus* (Figs 1a–d, 2a–c) with OOL more than three times as long as OPL (Fig. 1b); epicnemium concealed (Fig. 1d); notauli incomplete, reaching about 0.75× length of mesoscutum (Figs 1b, 2c); fore wing with one dark transverse band (Figs 1a, 2c); petiole distinctly visible (Fig. 1a); enlarged claw (Figs 1e, f, 2d, 4a) with one long row of small teeth, in addition to one lamella; protarsomere 5 (Figs 1e, f, 2d, 4a) with distal apex broad and dark pigmented, with one preapical lamella and inner band, without bristles on inner margin.

Description of the female (Figs 1–4a)**.** Fully winged (Figs 1a–d, 2a–c); length 2.8–3.2 mm (holotype 3.2 mm). Holotype ferruginous-black; paratype black. Antenna clavate (Fig. 1a, b), without ADOs; antennomeres in following proportions: 9:6:6:5:5:4.5:4.5:4.5:4.5:6; antennomere 9 slightly longer than broad (4.5:3). Head dull, completely granulate, not reticulate rugose; frontal line complete; occipital carina complete; POL = 3; OL = 2; OOL = 5; OPL = 6.5; TL = 6; greatest breadth of lateral ocellus shorter than POL (2:3). Mandible quadridentate, with one

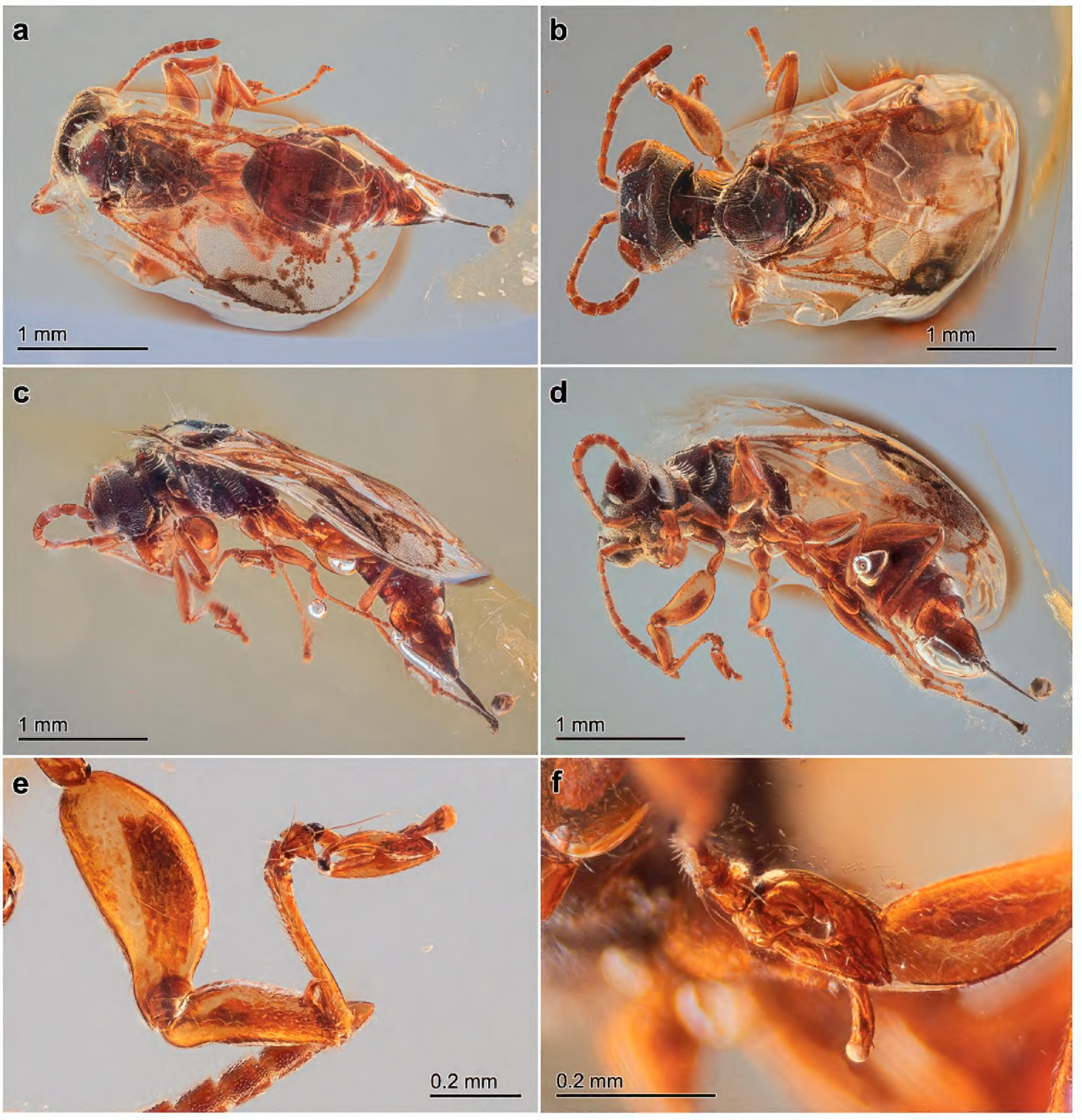

Figure 1. Stereomicroscopical images of *Bocchus rex* sp. nov., female, holotype (= specimen 1) **a, b** habitus, dorsal view **c** habitus, lateral view **d** habitus, ventrolateral view **e** fore leg **f** chela.

smaller intermediate tooth (Fig. 1d). Mesosoma longer than head (18:7), shorter than metasoma (18:23). Pronotum crossed by strong transverse impression, with sculpture not distinct, laterally with some longitudinal keels; pronotal tubercle reaching tegula. Mesoscutum dull, granulate. Notauli incomplete, reaching about 0.80× length of mesoscutum (Figs 1b, 2c). Sculpture of mesoscutellum and metanotum not distinctly visible. Epicnemium concealed (Fig. 1d). Metapectal-propodeal complex not distinctly visible. Fore wing with one dark broad transverse band (Figs 1a, 2c); distal part of 2r-rs&Rs vein much longer than proximal part (17:5). Petiole very long, much shorter than rest of metasoma (4:19). Proleg ratio: 12 (procoxa): 10 (protrochanter): 24 (profemur): 17 (protibia): 13 (protarsomere

1): 2 (protarsomere 2): 3 (protarsomere 3): 7 (protarsomere 4): 11 (protarsomere 5). Enlarged claw (Figs 1e, f, 2d, 4a) with one long row of small teeth (number not distinct) + one lamella. Protarsomere 5 (Figs 1e, f, 2d, 4a) with distal apex broad and dark pigmented, with one preapical lamella and inner band, without bristles on inner margin. Rudimentary claw present, although hardly visible. Mesoleg ratio: 9 (mesocoxa): 4 (mesotrochanter): 19 (mesofemur): 21 (mesotibia): 30 (tarsus). Metaleg ratio: 10 (metacoxa): 6 (metatrochanter): 27 (metafemur): 30 (metatibia): 25 (tarsus). Tibial spurs 1, ?, 1.

Male. Unknown.

Hosts. Unknown.

Etymology. Bocchus was the name of two kings of Mauretania (the first being father-in-law to the Numidian King Jugurtha) and *rex* is an appropriate epithet of this nice species with its regal look.

State of preservation of paratype (= specimen 2)**.** The head and thorax are well preserved but each have a fissure dorsally (Fig. 3c, e). The metasoma has been completely crushed (Figs 2c, 3a, c, e, g, Suppl. material 1: Video S1). Its size and form can be roughly estimated from the cavity formed in the amber. However,

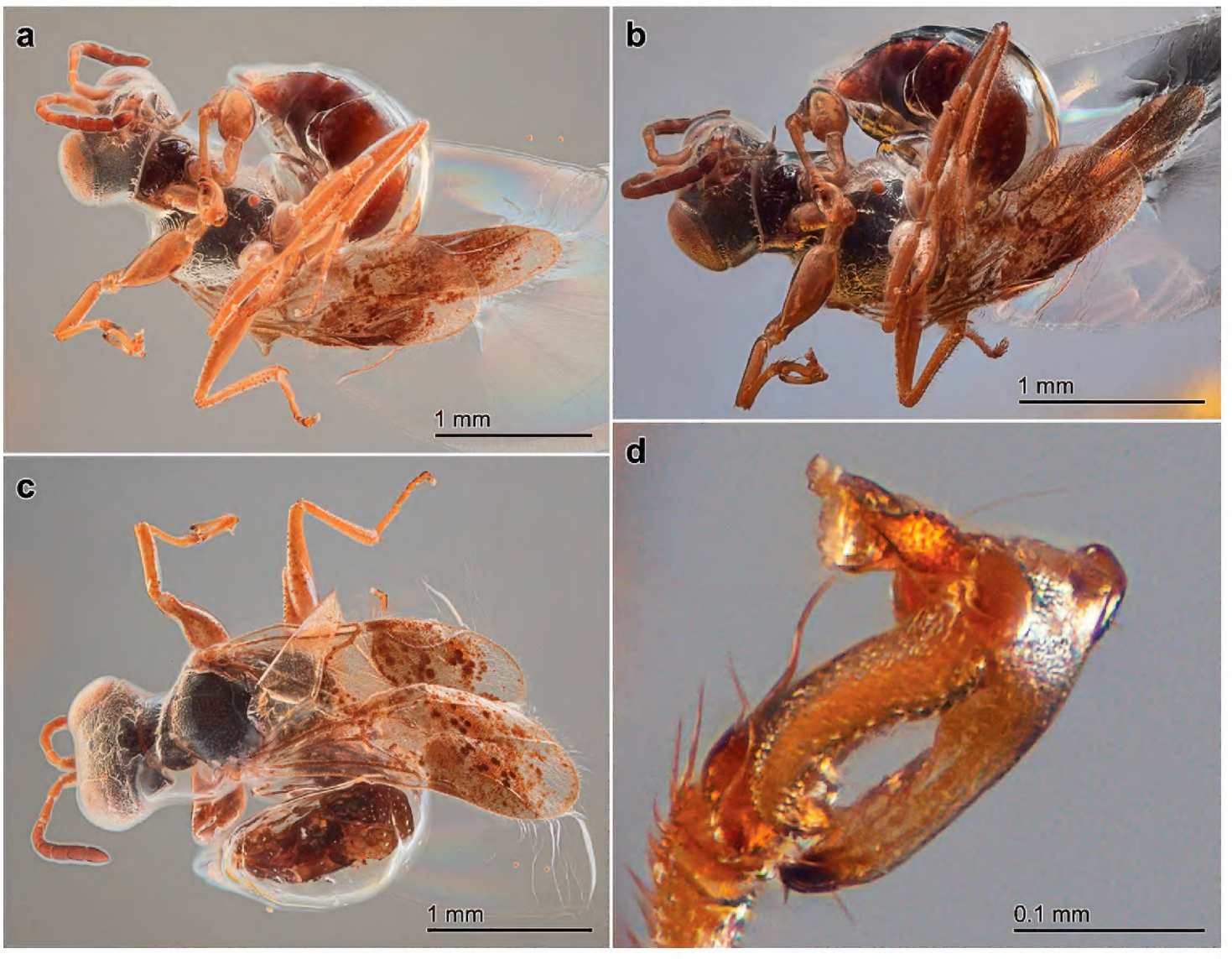

Figure 2. Stereomicroscopical images of *Bocchus rex* sp. nov., female, paratype (= specimen 2) **a, b** habitus, ventral view **c** habitus, dorsal view **d** chela.

cavities are also present laterally between the head and the thorax (Figs 2a–c, 3a, c, e, g, i, Suppl. material 1: Video S1). Unfortunately, the resolution of the SR-μCT scan was too low to 3D-reconstruct the chelae in great detail. In the head, the partially preserved optical ganglion complex, presumably the optic lobes (= medullae), is clearly visible (Fig. 3b, d, f, h, j, Suppl. material 1: Video S1). It is the second report of optic lobe preservation for Rovno amber arthropods (cf. fig. 1 of Sukhomlyn et al. 2022). Other internal structures are partially preserved; however, it is unclear whether they belong to the optical system or different brain regions, or are partially preserved muscles of the mouthparts (Fig. 3b, d, f, h, j, Suppl. material 1: Video S1). In addition, many muscles in the thorax, the legs and, occasionally, in the metasoma are still preserved (Fig. 3b, d, f, h, j, Suppl. material 1: Video S1). However, as the depicted set of muscles is by no means complete and plays no role in species identification, it will not be discussed further here.

Remarks. After the description of *Bocchus rex* sp. nov., the key published by Perkovsky et al. (2020) can be modified as follows.

Key to the Cretaceous and Paleogene species of the genus *Bocchus* Ashmead, 1893

Female:

1 Petiole very short, almost absent (cf. fig. 4 of Perkovsky et al. 2020) ..... ***B. cenomanianus* Olmi, Rasnitsyn & Guglielmino**

– Petiole distinctly visible, one sixth to one ninth of rest of metasoma (cf. fig. 1 of Perkovsky et al. 2020; Fig. 1a) **2**

2 Enlarged claw with teeth present only in the distal half of the inner margin (Fig. 4c) ..... ***B. schmalhauseni* Perkovsky, Olmi, Vasilenko, Capradossi & Guglielmino**

– Enlarged claw with teeth distributed along the entire inner margin (Figs 2d, 4a, b) **3**

3 Head with OOL about 62% of OPL; notauli complete, posteriorly separated (cf. fig. 9 of Perkovsky et al. 2020); protarsomere 5 with distal apex slender and not pigmented, with two bristles on inner margin (Fig. 4b) ..... ***B. primaevus* Martins & Melo**

– Head with OOL about 77% of OPL (Fig. 1b); notauli incomplete, reaching about 0.80× length of mesoscutum (Figs 1b, 2c); protarsomere 5 with distal apex broad and dark pigmented, without bristles on inner margin (Fig. 4a).. ***B. rex* sp. nov.**

Male:

Unknown.

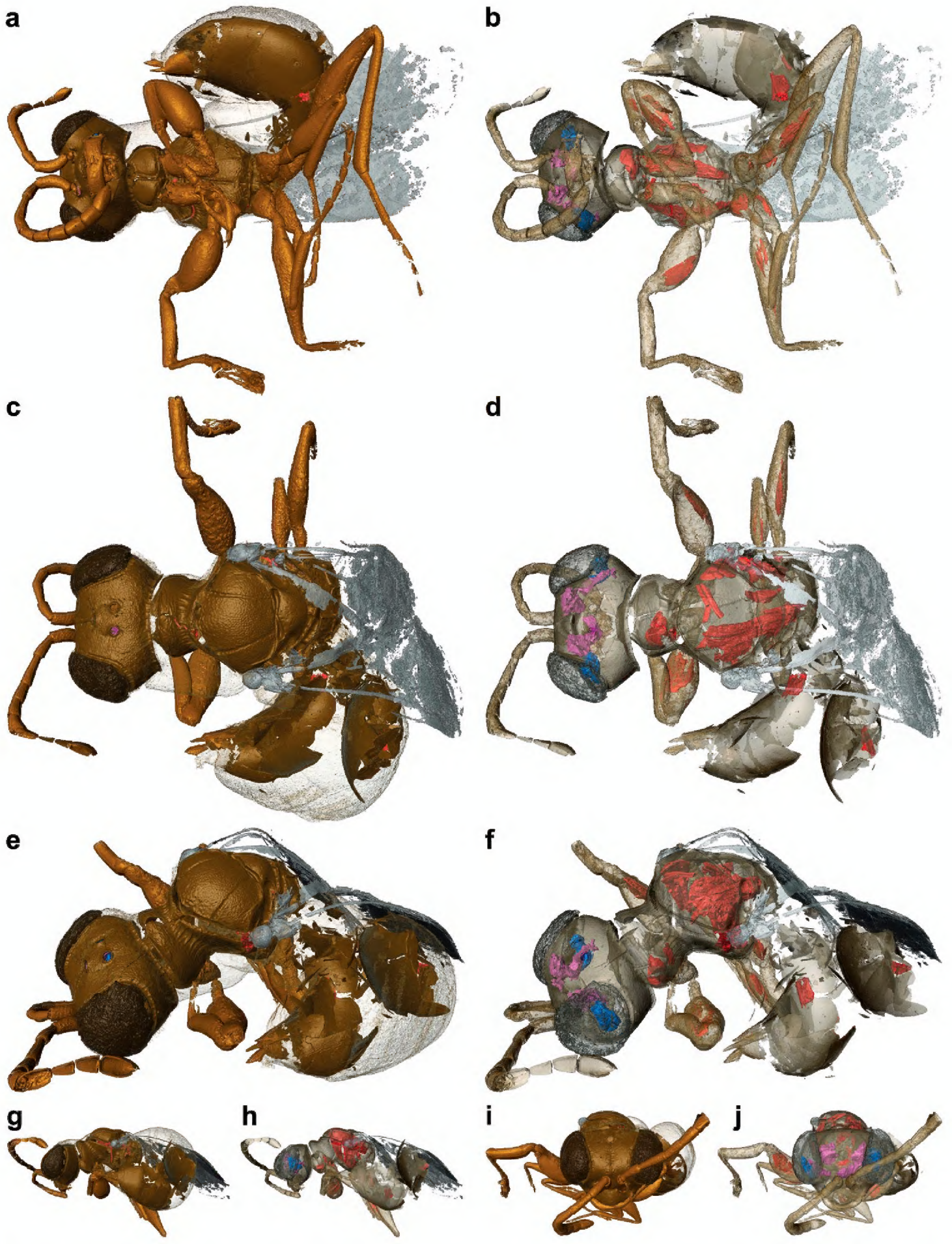

Figure 3. Segmented 3D model of *Bocchus rex* sp. nov., female, paratype (= specimen 2) based on SR-μCT data (perspective view; cf. Suppl. material 1: Video S1; parts of the left antenna and the tarsus of the right hind leg are outside of the dataset) **a, b** ventral view **c, d** dorsal view **e, f** dorsolateral view **g, h** lateral view **i, j** frontal view. The cuticular elements in a, c, e, g, i are depicted in various shades of brown, whereas the cavity of the wasp in the amber is shown as being semi-transparent. The partially preserved optical ganglion complex is shown in blue, the potential brain regions or head muscles in purple, and the muscles (in the thorax, the legs and the metasoma) in red, whereas the cuticular elements in b, d, f, h, j are semi-transparent and the cavity in the amber is omitted.

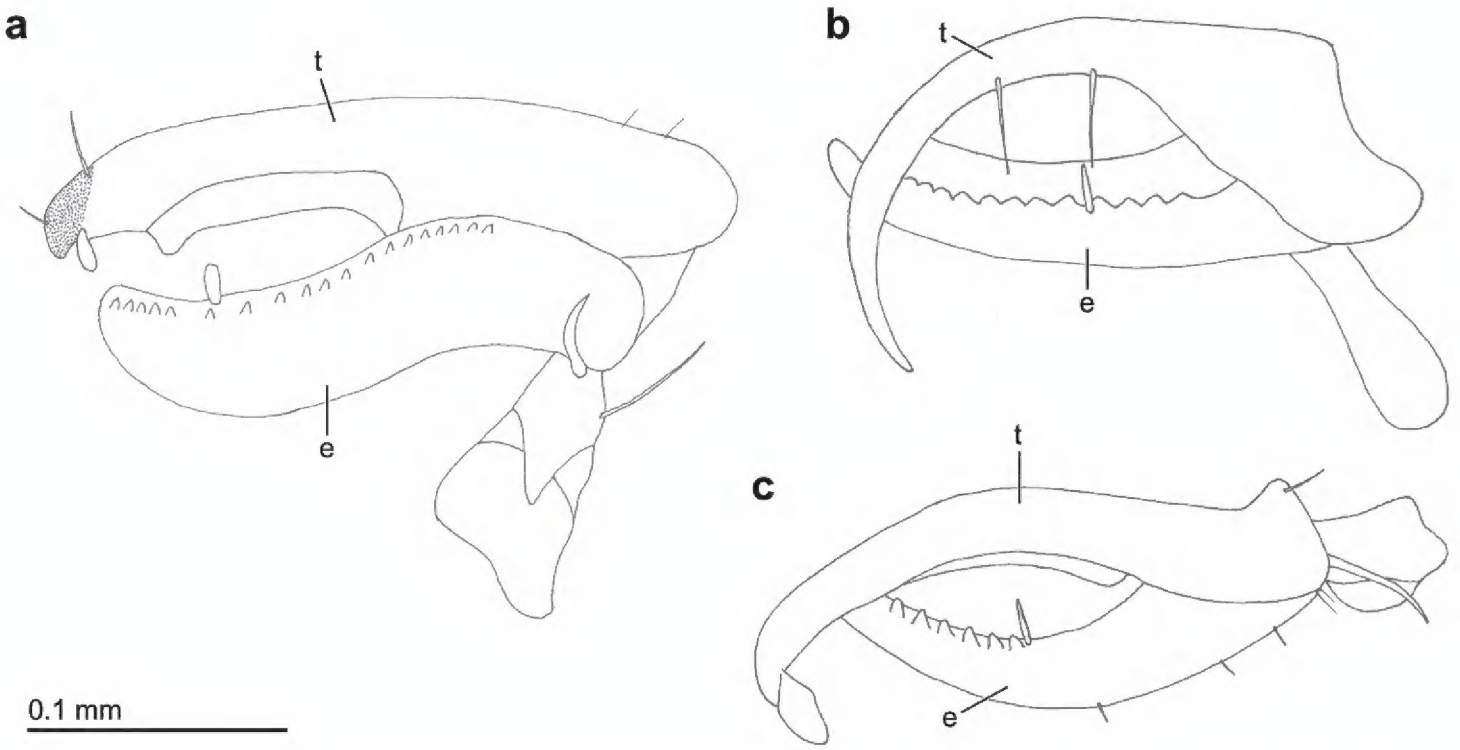

Figure 4. Schematic drawings of chelae of species of *Bocchus* known from amber **a** *Bocchus rex* sp. nov. **b** *B. primaevus* Martins & Melo (from Perkovsky et al. 2020) **c** *B. schmalhauseni* Perkovsky, Olmi, Vasilenko, Capradossi & Guglielmino (from Perkovsky et al. 2020). Abbreviations: e, enlarged claw; t, protarsomere 5.

Discussion

The above-described new species is attributed to the genus *Bocchus* (Hymenoptera, Dryinidae, Bocchinae) because of the following characters: ocelli present; epicnemium concealed; protarsus chelate; chela with rudimentary claw.

The genus *Bocchus* includes 103 species present in all zoogeographical regions, except for Antarctica (Perkovsky et al. 2020). The hosts of *Bocchus* are Tropiduchidae and Caliscelidae (Hemiptera, Auchenorrhyncha) (Guglielmino et al. 2013). These two families of planthoppers are only known from the Cenozoic (Perkovsky et al. 2020).

Fossil species of *Bocchus* are known from the Cenozoic (i.e. from Baltic and Rovno amber) as follows: *B. primaevus* Martins & Melo, 2019 (2021) from upper Eocene Baltic amber, Priabonian, 35–38 Ma; *B. schmalhauseni* Perkovsky, Olmi, Vasilenko, Capradossi & Guglielmino, 2020 and *B. rex* sp. nov. from Rovno amber, coeval of Baltic amber. Probably the hosts of the above three species were Tropiduchidae, as they are known from both Baltic and Rovno amber (Perkovsky and Bogdasarov 2009; Perkovsky et al. 2020; Olmi et al. 2022). The oldest tropiduchid is known from the lower Eocene of the Green River Formation (CO, USA) (Shcherbakov 2006). Fossil Caliscelidae are also known from the Cenozoic, but only from Dominican amber (Burdigalian, lower Miocene; 16–20 Ma) (Bourgoin et al. 2015).

A fourth species has been attributed to the genus *Bocchus*: *B. cenomanianus* Olmi, Rasnitsyn & Guglielmino, 2010. It is a compression fossil in extremely bad condition from Obeschchayushchiy, Magadan region, Russian Federation (Santonian-Campanian, Upper Cretaceous, 72–85 Ma). However, its attribution to *Bocchus* is doubtful, because Caliscelidae and Tropiduchidae are not known from the Cretaceous (Perkovsky et al.

2020). Of course, the host at the Obeschchayushchiy site might well have belonged to other families of planthoppers. However, according to Perkovsky et al. (2020), angiosperms (hosts of extant Caliscelidae and Tropiduchidae) were extremely rare at that site. On the other hand, no evidence exists for possible *Bocchus* hosts feeding on gymnosperms or ancient ferns predominant at the Obeschchayushchiy site (Nadein and Perkovsky 2018; Perkovsky et al. 2020). Hence, *B. cenomanianus* might have been misidentified.

The new *Bocchus* described here is the first hymenopteran and seventh named fossil arthropod from the Volyn Region, Ukraine (Martynov et al. 2021; Telnov et al. 2021; Legalov et al. 2022). The discovery of *B. rex* is indicative of the richness of *Bocchus* species in Rovno amber in comparison with Baltic amber: two species (29% of all dryinid species) in Rovno amber versus one (4.8% of all dryinid species) in Baltic amber. In addition, one specimen from Varash district could not be determined to the species level. This difference might be related to the climate of the Rovno amber forest being warmer than that of the Baltic amber forest (Kupryjanowicz et al. 2022; Yamamoto et al. 2022; and references therein), especially since their potential hosts (i.e. Tropiduchidae) are mainly tropical and subtropical (Bourgoin 2020).

To date, *Bocchus* is the most common genus of Dryinidae in Rovno amber fauna and Bocchinae is the dominant subfamily (44.4% of specimens versus 33.3% for *Dryinus* and Dryininae) at the specimen level. This is unusual, as Dryininae strongly dominate not only in Baltic amber, but also in Kachin (33 Dryininae species according to Olmi et al. 2022) and Dominican (ten Dryininae species versus one belonging to Bocchinae; Martynova et al. 2019; Martins and Melo 2020) ambers, both at the specimen and species levels.

The biology of *Bocchus* species is poorly known so far. The species with known biology live in open environments. An even more important reason for the abundance of *Bocchus* is that open environments were more common in the Priabonian Ukraine than in the Baltic amber forest (Lyubarsky and Perkovsky 2012; Perkovsky 2013; Lyubarsky and Perkovsky 2019; Dietrich and Perkovsky 2020).

A comparison with the extant *Bocchus* species shows that their body shape is similar to the species known from European Eocene amber. The chela of *B. rex* and *B. schmalhauseni* follows the same general scheme as in the extant species. The only difference can be observed in the chela of *B. primaevus* and is attributable to the anomalous long and slender protarsomere 5 (Fig. 4b). A similar type of protarsomere 5 has not been found in any extant or fossil species of *Bocchus*. However, the significance of this anomalous chela remains unknown.

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Supplementary material 1

Video S1

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Data type: video file (mp4)

Explanation note: Animation of the rotating segmented 3D model of *Bocchus rex* sp. nov., female, paratype (= specimen 2) based on SR-μCT data (perspective view; cf. Fig. 3; parts of the left antenna and the tarsus of the right hind leg are outside of the dataset). The cuticular elements are depicted in various shades of brown, whereas the cavity of the wasp in the amber is shown as being semi-transparent. The partially preserved optical ganglion complex is shown in blue, the potential brain regions or head muscles in purple, and the muscles in red.

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